FOREST INSECT AND DISEASE MANAGEMENT

Environmental Impacts of Acephate Insecticide (Orthene®)

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INTRODUCTION

Acephate (O,S-dimethyl acetylphosphoramidothioate) is a white crystalline solid with a melting point of 92-93° C, a very low vapor pressure (2×10^{-6}mm Hg at 25° C) and very high solubility in water (65%) (Leary and Schinski, 1972; Crossley, 1970).

Acephate, formulated as Orthene Forest Spray, a 75% soluble powder, is registered by the Environmental Protection Agency for use against the gypsy moth. Various applications at 0.5 lbs. a.i./acre have shown effective reduction of gypsy moth populations and foliage protection to host trees (Herbaugh et al., 1975; LOTEL, 1975; ERA Laboratories, 1976).

Orthene is an organic phosphate insecticide of moderate persistence (4-15 days) with residual systemic activity and a cholinesterase inhibition mode of action (Chevron, 1976).

As with any material foreign to the forest environment, Orthene has a degree of impact on our bioshphere. However, Orthene has a very low toxicity to fish and mammals; Orthene residues degrade rapidly in soil and water, and do not persist or bioaccumulate in organisms or along the food chain.

Information on the environmental impacts of acephate (Orthene®) insecticide compiled here is presented here as an aid for those engaged in suppression of the gypsy moth in the Northeast.[1]

LIFE OF ORTHENE IN THE ENVIRONMENT

Orthene is quickly degraded in soil (Tucker, 1972a; Leary, 1972). The rate of breakdown has been studied in laboratory tests using nine common soil types. Orthene was added at 1.0 and 10.0 ppm levels to soils wet to field capacity, and aged under aerobic conditions. As shown in the following table, Orthene half-lives ranged from 0.5 to 4 days in 8 of the 9 soils. Only the very high organic-content muck exceeded one week (Chevron, 1973).

Soil Type	*Half-Life (days)*	
	1.0 ppm	*10* ppm
Clay	1½	1½
Clay (high pH)	½	½
Clay (low pH)	—	1½
Loamy sand	1	1
Loamy sand	—	4
Sandy clay loam	½	1
Silty clay loam	—	2
Muck	6	13

From kinetic reaction studies, it has been determined that about 5-10% of Orthene degrades into Ortho 9006 (O,S-dimethyl phosphoramidothioate) which is itself a registered insecticide under the tradename Monitor®. The remaining 90-95% of the Orthene degrades directly into innocuous salts (Tucker, 1972b). No other metabolites of toxicological significance have been observed (Tutass, 1968a). Ortho 9006 is also rapidly degraded in soil and has a half-life of 2 to 6 days (Leary and Tutass, 1968).

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Both compounds degrade more rapidly in wet soil than in dry soil. In loam with a 1.6% moisture content, the half-life of Orthene and Ortho 9006 is 11 and 1½ days, respectively, which drops to 3 and ½ days respectively in 12.9% moisture content loan. Similarly, in sandy clay loam with 6.5% water, the half-lives are 3 and 0.67 days for Orthene and Ortho 9006, which decreases to 1 and 0.25 days respectively in 20.3% moisture soil (Tucker, 1972a).

The decomposition of both Orthene and Ortho 9006 residues in soil is primarily biological in nature, due to soil microorganisms. In both clay and silty clay loam, the half-life of Orthene was 1.5 days under nonsterile conditions, while sterile soil retained 80-95% of the dose. Four days after treatment, the sterile soil still contained 80-95%, while the non-sterile soil decreased to only 15% (Tucker, 1972a). Under anaerobic conditions, the degradation rate is somewhat slower, with less radio-labeled CO_2 released, but with more of the degradation products incorporated into the microorganisms than under aerobic conditions (Tucker, 1972c).

Laboratory studies using both column leaching and soil thin-layer techniques have shown that Orthene and Ortho 9006 are readily moved by water in soil with little or no retention by the soil particles (Tucker, 1971; Tutass, 1968b). There is essentially no difference in the rate of leaching of Orthene in soil wet to field capacity or in air-dried soil (Tucker, 1972d).

The leaching of aged soil residues was also studied using radio-labeled Orthene applied at 2 ppm. The soil containing the residues was incubated for 20 days; about 15% of the total applied remained in the soil after the incubation period. The soil was placed on top of columns of the same soil, but untreated, and leached using 0.5 inches of water daily for 46 days. Only 0.3% of the applied radio-carbon was recovered in the leachates. Following leaching, the residual radioactivity was found to be almost entirely in the top 3 inches of the soil column, and only 0.1% of the original dose could be extracted from the leached soil. Therefore, after aging, the Orthene residues were not leachable, and were not present as Orthene or Ortho 9006, but incorporated into the natural constituents of the soil (Warnock, 1972a).

In another aging test, soil samples were sprayed with Orthene at 9 lbs a.i./acre and allowed to age undisturbed except for watering in a greenhouse. After 21 weeks, the soil contained 0.005 ppm Orthene or less, which was about 0.5 percent of the applied dose. The remaining residues were entirely leachable, with no bound Orthene or Ortho 9006 present in the soil (Tucker, 1972e).

Field tests were conducted to determine Orthene and Ortho 9006 residues in runoff water after application at 1 lb a.i./acre to cultivated lettuce fields. Immediately after treatment, 2 inches of water from overhead irrigation systems were applied and run-off collected in one corner of the sloping field. Small, but significant residues of Orthene were found in both the runoff water (0.06—0.08 ppm) and the associated soil particles (0.10-0.13 ppm). No Ortho 9006 residues were detected (Chevron, 1973).

In water systems the half-life of Orthene residues is 46 days at a buffered pH of 7, increasing to 55 days at pH 5, and decreasing to 16 days at pH 9, at a constant 21°C temperature (Crossley, 1972a). However, in field tests Orthene residues dissipated much more rapidly. Ponds, in Florida and Iowa, were treated with 0.1 ppm, and samples of water, bottom mud and submerged vegetation monitored. Orthene residues in water decreased quickly, with a half-life of 3 to 15 days. In the bottom sediments, the half-life ranged from 1 to 3 days. No Ortho 9006 was detected at any time (Chevron, 1973).

Orthene and Ortho 9006 move readily in soil with water; however, because they are rapidly degraded in soil, a field test was conducted to determine if residues would percolate into ground water systems. This was an extreme case as the sandy soil was very porous, the rainfall (both natural and artifical) was heavy, and the plot treated four times with 1 lb a.i./acre and finally with 3 lbs a.i./acre. After each rainfall, ground water samples at several intervals were collected and analyzed.

The amount of Orthene found in water at 1 ft. varied from 0 to 2 ppm (for the 3 lb/acre application, 0-4 hours after treatment). No Orthene residues were detected in any sample of water or soil taken 2½ feet or deeper. Residues were detected in the soil, but only at shallow depths, with a maximum at 6-12 inches (Chevron, 1973).

Following treatment at 0.5 lbs a.i./acre for control of the gypsy moth, Orthene residues were monitored in soil and water samples from a Pennsylvania hardwood forest. A maximum of 0.10 ppm was found one day after treatment in the exposed soil samples, which fell below the limits of detection (0.02 ppm) within five days. Other, unexposed soil samples contained no detectable residues. Pond water and bottom sediment both contained 0.01 ppm Orthene one day after spray, which was the limit of sensitivity, and were undetectable by day three (LOTEL, 1975).

Orthene has a longer half-life on foliar surfaces than in soil or water. Orthene and Ortho 9006 are adsorbed onto and/or absorbed into leaf surfaces. In studies using lettuce, broccoli and cotton leaves, only an average of 5% of the applied Othene could be washed off leaves 3, 7 and 14 days after treatment at 2 lbs a.i./acre (Chevron, 1973).

Translocation studies with radioactive Orthene have shown that there is only slight systemic movement of the chemical from a treated leaf to other parts of the plant, including roots and tubers. However, both Orthene and Ortho 9006 are readily picked up by plants from treated soil. From soil containing 10 ppm, radish tops contained 46 ppm Orthene and 12 ppm Ortho 9006, although the roots contained only 1.9 ppm Orthene. These studies indicate that Orthene residues are moved to the leaves in the transpiration stream and accumulated there (Crossley, 1972b; Warnock, 1972b; Tutass, 1968b).

The half-life of residues on forest leaves following aerial application at 0.5 lbs a.i./acre for gypsy moth control was approximately 2 days. By 20 days after treatment, Orthene leaf residues were less than 0.3 ppm, and by 32 days, all but 2 of 25 samples were less than 0.02 ppm, the limit of detection (LOTEL, 1975).

Separate laboratory studies on the fate of Orthene residues in food chain organisms, and in model ecosystems, indicate no bioaccumulation. The marine diatom *Cylindrotheca fusiformis* and the fresh water flea *Daphnia magna* were exposed to 1, 10 and 100 ppm Orthene and neither organism accumulated residues to any extent (Tucker, 1972f; Tucker, 1972g).

Bluegill sunfish, *Lepomis macrochirus,* were continuously exposed to 1.0 or 0.01 ppm Orthene for 35 days, and tissue samples analyzed periodically to determine the rate and extent of ^{14}C-residue accumulation. After the exposure period, the fish were transferred to untreated water for 14 days. The maximum tissue concentration of radio-labeled residues in the edible portion was about 10x the concentration in water. Upon transfer to uncontaminated water, fish exposed at both levels eliminated more than 50% of the residues in the edible portion within 3 days (Sleight, 1972).

The fate of radioactive Orthene in a Metcalfe model ecosystem containing algae, daphnids, emergent plants, insects and mosquito fish concluded that residues were not persistent and did not biomagnify along the food chain or accumulate in any ecosystem component. Orthene residues were found only in water; other traces detected were metabolic fragments naturally incorporated into living tissues; and no residues or traces were detected in fish tissues, the organism at the top of this food chain (Booth and Yu, 1972).

TOXICOLOGY

Mammalian acute toxicities are quite low for Orthene: the rat oral LD_{50} is 1494 mg/kg for the 75% soluble powder formulation. The acute dermal and inhalational toxicities are also quite low, while no irritation occurred on intact rabbit skin and no skin irritation or sensitization was observed in guinea pigs (Chevron, 1973). The following table is a summary of acute mammalian toxicity studies:

Orthene Acute Mammalian Toxicity

	Acute Oral LD_{50}
Rat (male)	945 mg/kg (technical)
Rat (female)	866 mg/kg (technical)
Rat	1,494 mg/kg (75S)
Mice	361 mg/kg (technical)
Rabbit	700 mg/kg (75S)
	Acute Dermal LD_{50}
Rabbit	2,000 mg/kg (technical)
Rabbit	10,250 mg/kg (75S)
	Acute Inhalational LC_{50}
Rat	12.1 mg/1—1 hour
Rat	No effect after 4 hours exposure to saturated vapor

The subacute Orthene toxicities were found to be similarly low: 90 day feeding studies in the rat showed no significant toxic symptoms other than a slight lowering of blood and serum cholinesterase activity at 30 ppm in the diet. At 300 ppm, there was no abnormality in weight gain, food consumption, survival, blood and urological or pathological studies. The same was found to be true for dogs exposed to the same dose levels in the diet (Chevron, 1973).

The metabolic fate of Orthene was determined following single oral doses in the rat, goat, and quail using radio-labeled material, and with nonradioactive doses for meat and milk in the cow, meat in the hog, and meat and eggs in the chicken and quail (Lee, 1972; Crossley and Lee, 1971; Warnock, 1973; Tucker, 1973a, b; Leary and Lee, 1972).

The metabolism in all species tested is essentially the same. Excretion is rapid and virtually complete. Most of the excretion took place in the first 12 hours and only a low level of elimination was observed thereafter. The main route of excretion is via urine in mammals and feces in birds. Most of the remaining dose was found in the breath. Only traces were detected in the tissues, and none of these were concentrated in any one organ or tissue. In the mammalian studies, the residues were identified as 75% unchanged Orthene; no Ortho 9006 was detected, either in urine or milk (Tucker, 1973a).

At 3 mg/kg, the maximum dose tested, Orthene does not cause teratogenesis in rabbits. The study showed no external, weight or survival abnormalities at this level. A study in which pregnant rats were exposed to up to 200 mg/kg also showed no differences in fetal body weight, external, skeletal, or internal development to the test animals.

A 3-generation rat reproduction study showed that 30 ppm Orthene in the diet was a no effect level. At the 100 and 300 ppm levels, mating indices were reduced, and second generation fertility index was lowered. However, the third generation was normal, and other reproduction parameters were essentially the same for test and control groups. A two year feeding study, also with rats, found that levels of 100 and 300 ppm in the diet depressed body weight slightly, and noted slight to moderate depression of cholinesterase activity. There were no other significant differences between treated and control animals for other parameters, including food consumption, hematology, gross and microscopic pathology, or tumor incidence or classification of fish and wildlife (Chevron, 1976):

Orthene does not cause mutagenic or neurotoxic effects to mice in standard dominant lethal mutation studies. Long-term exposure studies in mice, rats and chickens showed no disturbance in the spontaneous tumor profile and no histopathological abnormalities at rates of 30, 100 and 300 ppm in the diet.

Orthene Acute Wildlife Toxicity

The table below lists the acute toxicities of Orthene to a representative cross-section of fish and wildlife (Chevron, 1976):

96-Hour LC_{50}

Rainbow trout	1,000 ppm (75S)
Bluegill sunfish	2,050 ppm (75S)
Largemouth bass	1,725 ppm (75S)
Channel catfish	2,230 ppm (75S)
Mosquito fish	6,650 ppm (75S)
Goldfish	9,550 ppm (75S)

Acute Oral LD_{50}

Mallard ducks	350 mg/kg (technical)
Ringneck pheasants	140 mg/kg (technical)
Chickens	852 mg/kg (technical)

TERRESTRIAL ORGANISMS

Man and His Food

A monitoring and medical study was done on several men occupationally exposed to Orthene in a pilot plant where Orthene was being produced or in a formulation lab where large batches were formulated (Pack, 1972a). Their urine was monitored for Orthene and metabolites and complete medical studies were made. Although concentrations of up to 5 ppm were detected in the urine, none showed any effect in their health; there was no effect on their blood cholinesterase levels, a sensitive indicator of organophosphate exposure.

In a second study, field research workers were monitored (Pack, 1972b). Analysis of their urine also showed exposure to Orthene, but to a much lesser extend than those in the pilot plant.

Cotton field plots were sampled to determine potential exposure of field workers to Orthene residues (Tucker, 1972h). Plots were treated with 1 or 2 lbs a.i./acre with 5 to 8 weekly applications. Leaf samples showed that wiping approximately one hour after spray removed up to 30% of the Orthene contained in or on the leaves. Gloves and shirt sleeves worn by workers hand harvesting the treated cotton showed a sharp decline in residues with the interval of reentry time exposure. In the seventh day after the last treatment, there was a ten-fold decrease in residues on the gloves. Residues of the metabolite, Ortho 9006, in the gloves and shirt sleeves similarly declined.

To date there have been no problems of intoxication or complaints resulting from the various field development programs using Orthene. When handled properly, Orthene poses no health hazard to persons formulating, spraying, or working in sprayed forests.

To determine if Orthene and/or Ortho 9006 could be transferred to young in nursing mammals, cows and goats were dosed with Orthene, Ortho 9006 and mixtures (Crossley and Lee, 1971; Tucker, 1973a). During dosing with Orthene, small amounts of Orthene appeared in the milk. Forty-eight hours after dosing, the amount decreased to 0.01 ppm or less. No Ortho 9006 was detected in the milk, either from dosing with Orthene or Ortho 9006 itself. Although a small proportion of the ingested Orthene is found in milk, there was no concentration, as occurs with DDT; and further excretion into milk stops immediately after exposure stops.

Orthene and Ortho 9006 were not concentrated in the flesh or tissues including fat of mammals, either during or after dosing. These studies included meat and milk in the cow (Tucker, 1973a), meat in the hog (Tucker, 1973b), and meat and eggs in chicken (Leary and Lee, 1972). The main route of excretion is in the urine of mammals and feces of birds, with about 75% representing unchanged Orthene. Most of the remaining dose was found in the breath, with only traces found in the milk (of cows and goats) or eggs (of quail and chickens).

Other Mammals

The effects of an aerial application of Orthene at 0.5 lbs a.i./acre were studied on native small mammal populations (LOTEL, 1975). Results obtained from 786 small mammal carcasses and 181 live trappings failed to reveal any overt deleterious effects of the spray. The most abundant mammals trapped were the white-footed deermouse *Peromyscus leucopus,* the short-tailed shrew *Blarina brevicauda,* and the red-backed vole *Clethrionomyus gapperi.*

Although detectable amounts of Orthene and Ortho 9006 residues were found on the pelage and in the stomach contents of most of the small mammals examined, no detectable residues were present in any tissue samples.

Indices of population density based on trap success and the number of recaptured marked individuals showed that no significant increase in mortality or emigration occurred in the treated areas. *P. leucopus* adults especially males, were fewer in number on the treated areas, and the mean body length and mean testes weight were smaller for those males captured about one month postspray. However, the number of pregnant or lactating females and uterine weights and litter parameters were not influenced by the spray.

Peromyscus, Blarina and *Clethrionomys* all utilized a temporarily abundant arthropod food source that occurred on treated areas following the Orthene spray. No significant long-term change in food availability or food consumption occurred. No effect on the growth rate of juvenile animals was detected.

Birds

The effects of an aerial application of Orthene at 0.5 lbs a.i./acre on native forest songbirds in New York were studied (LOTEL, 1975). Singing male censuses were used to examine the populations and territories of canopy-feeding and ground-feeding insectivores. No mortality of adults or nestlings was observed; census totals for most of the 17 species observed remained relatively constant.

Of the flycatcher group, the singing activity of the crested flycatcher *Myiarchus crinitus* declined significantly after spray; however, the wood peewee, *Contopus virens,* did not. And territories were not abandoned by either species.

The species dependent on foliage invertebrates, vireos and tanagers, were most affected of all birds observed. Toward the center of the treatment plot there was no song activity at all by the red-eyed vireo *Vireo olivaceus* and the soliatry vireo *Vireo solitarius,* suggesting some territory abandonment. However, vireo nests with nestlings under observation in this area showed a weight in the nestlings.

Of the ground feeders, the singing frequency for the towhee, *Pipilo erythrophthalmus,* thrushes, *Hylocichla* spp., and junco, *Junco hyemalis,* did not change detectably and territories were definitely not abandoned.

Soil Fauna

A study was conducted to determine the effect of Orthene and Ortho 9006 on soil microorganisms (Focht and Joseph, 1972). A Hanford loamy sand, A Domino silt loam and an Altamont clay loam were treated separately with three repeated applications of 20 ppm Orthene and Ortho 9006 over a 50 day period. There was no difference in fungal, bacterial or actinomycete populations between treatment and control, an no effect was shown on the respiration, ammonification, nitrification and sulfur oxidation rates within the soils. Replicate plating failed to isolate any bacteria that were adversely affected either by Orthene or Ortho 9006.

Orthene applied to forests at 0.5 lbs a.i./acre for control of the gypsy moth had no discernible effect on total soil bacteria populations, actinomycetes or nitrogen-fixing bacteria (LOTEL, 1975).

Earthworms were tested by exposure to soil treated with Orthene at the equivalent rate of 2 lbs a.i./acre. The concentration of Orthene residues in the worm was one-half to one-eighth the concentration in the soil. The residues in the earthworms disappeared when the worms were transferred to uncontaminated soil (Tucker, 1972i).

Non-Target Insects

Orthene is toxic to bees present in the affected areas at the time of application. However, in a comparative test with worker honey bees, Orthene was less toxic than malathion, but slightly more toxic than carbaryl (Chevron, 1973).

Tests were conducted to determine the relative toxicity of Orthene, carbaryl and parathion to 5 species of beneficial predatory insects (Byrne, 1972). Orthene was virtually inactive against the wasp *Chelonus blackburnii* which feeds on the pink bollworm, and the lacewing *Chrysopa carnea* which feeds on aphids and mites. Orthene was mildly or highly toxic to two wasps *Tachinaephagus zelandicus* and *Muscidifurax raptor,* and to the ladybug *Hippodamia convergans.*

The effect on non-target insects of an aerial application of Orthene at 0.5 lbs a.i./acre for control of the gypsy moth were monitored up to one month after treatment (LOTEL, 1975). It was concluded that lepidoptera larvae, diptera larvae and Hymenoptera, predominantly the family Formicidae, were adversely affected. The order Coleoptera was least affected, while diptera larvae showed the greatest decline in numbers; and there was a knock-down effect observed immediately after spray which affected all orders of arthropods collected. However, those populations which were depressed recovered to pretreatment levels within one month, and none were eliminated.

Plants

Orthene is not phytotoxic at the recommended dose for gypsy moth control, although 1 lb a.i./acre in 100 gallons sprayed to drip has caused marginal leaf burn or interveinal chlorosis on American elm, flowering crabapple and sugar and red maples (Chevron, 1973).

AQUATIC ORGANISMS

Fish

Orthene has an extremely low toxicity to fish. The most susceptible fish species tested was the rainbow trout *Salmo gairdneri* with a 96-hour TLm of more than 1,000 ppm. Other species tested include the largemouth bass *Micropterus salmoides* at 1,725 ppm; the bluegill sunfish *Lepomis macrochirus* at 2,050 ppm; and the channel catfish *Ictalurus punctatus* at 2,230 ppm (Chevron, 1976). Even multiple applications to open bodies of water could not reasonably approach these rates; an application at 0.5 lbs a.i./acre should theoretically result in 0.03 ppm in one foot of standing water.

A variety of native fish were captured, placed in an impoundment and observed for 2 weeks before and after an application at 0.5 lbs a.i./acre. Residue analysis was performed on water, sediment and fish edible tissues (LOTEL, 1975). There was no mortality or unusual behavior observed; no detectable Orthene or Ortho 9006 residues were found in the bottom sediment or fish tissues, and only 0.01 ppm Orthene was detected in water samples immediately after spray.

Invertebrates

An extensive set of replicated pre- and postspray samples was taken from a stream and a pond in Pennsylvania to determine the effect of an application of Orthene at 0.5 lbs a.i./acre to aquatic invertebrates. Only one group of organisms was significantly reduced in numbers during the post-treatment period, the Chironomidae. However, other, highly sensitive orders such as Plecoptera and Ephemeroptera apparently were not affected, and drift net samples demonstrated no increase in stream insect drift rates. It therefore seems unlikely that the decrease in Chironomidae was treatment related (LOTEL, 1975).

NON-LIVING ENTITIES

Water Supplies

Orthene residues degrade rapidly in natural waters, with a half-life of 3-15 days in ponds deliberately treated with 0.1 ppm (Chevron, 1973). Residues following an aerial application at 0.5 lbs a.i./acre in pond water were only 0.01 ppm and became undetectable within three days (LOTEL, 1975). Under operational spray conditions, open bodies of water will be avoided, and little contamination of reservoirs or other public water supplies is likely.

Soil

Orthene residues decompose in the soil with a half-life of ½ to 4 days (Chevron, 1973), degrading even faster in soils with a higher moisture content (Tucker, 1972a). Orthene residues leach easily from soil, and do not become bound to soil particles (Tucker, 1971). Exposed forest soil contained 0.02 ppm Orthene after an aerial application at 0.5 lbs a.i./acre, and were undetectable within 5 days (LOTEL, 1975).

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